

Effect of Steeping Corn with Lactic Acid on Starch Properties

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ABSTRACT

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Pasting and thermal properties of starch from corn steeped in the presence of lactic acid and at different steeping times (8, 16, 24, 32, and 40 hr) were investigated. Corn kernels were steeped at 52°C with 0.2% (w/v) SO₂ and with and without 0.5% (v/v) lactic acid. The isolated starch obtained by corn wet-milling was characterized by determining starch recoveries, retrogradation, and melting transition properties of the lipid-amylose complex by differential scanning calorimetry (DSC), and pasting properties by the Rapid Visco Analyser (RVA). Damaged granules and the starch granule size were determined by using microscopic techniques. Starches from corn steeped in the presence of lactic acid (LAS) were compared with control starch (CS) steeped without lactic

acid. Greater starch recoveries were obtained for LAS samples than for CS samples, and practically no damaged starch was present in the former preparations. The presence of lactic acid affected the RVA profiles and steeping time affected the viscosities of the starch suspensions. In general, the RVA parameters of LAS suspensions were lower than those of CS suspensions. No great modification of the thermal properties was observed; only a slight decrease in amylopectin retrogradation and in the melting enthalpy of the amylose-lipid complex was observed. Hydrolysis of the starch during steeping seems the most probable explanation to the starch modifications produced by lactic acid addition.

Wet-milling is an industrial process involving physical, chemical, biochemical, and mechanical operations to separate the principal components of the corn grain: starch, protein, germ, and fiber. Steeping kernels in dilute SO₂ solution (0.1–0.2%) at subgelatinization temperatures (45–55°C) is the first and most important step in the wet-milling process. Steeping time typically ranges between 24 and 52 hr. However, steeping is also capital-intensive and time-consuming because of the resistance of the seed coat and aleurone layer to water and SO₂ absorption (Watson and Sanders 1961). Therefore, this step plays an important role in the efficiency of corn wet-milling (Singh and Johnston 2002). The efficacy of the steeping operation depends on the rate of diffusion of steep-water and the disintegration of the protein network, which cannot occur in absence of SO₂ carried by water. Reduced steeping time decreases energy cost, increases plant capacity, and reduces the capital cost involved in constructing new wet-milling plants (Mehra et al 2000). Numerous investigations have focused on reducing steeping time by mechanical, chemical, or biochemical methods (Krochta et al 1981; Hassamean and Abdel-Wahed 1986; Meuser et al 1989; Eckhoff and Tso 1991; Steinke and Johnson 1991; Eckhoff et al 1993; Haros and Suarez 1999; Johnston and Singh 2001; Perez et al 2001). Nevertheless, steeping conditions affect the yield of starch recovery and may also induce physical and chemical changes in the starch granules.

The increased moisture content of grain during steeping decreases starch damaged starch during milling (Chiang and Yeh 2002). The steeping time influences hydration of the grain but not all corn types have either the same water diffusion rate and or the same rate of SO₂ diffusion (Haros et al 1995, 2001; Haros and Suarez 1999). The optimum steeping time depends, among other factors, on the horny endosperm proportion of the corn.

Lactic acid facilitates the separation of starch from the protein matrix and increases starch yields by recovering the horny endosperm starch in addition to the floury endosperm starch (Eckhoff and Tso 1991; Du et al 1996; Haros and Suarez 1999; Perez et al 2001; Manzoni et al 2002). However, information is scarce concerning the effects of steeping time and the addition of lactic acid on starch characteristics. Shandera and Jackson (1996) studied the effect of steeping temperature and concentrations of lactic acid

and SO₂ on starch functionality, finding that steeping conditions affected the physicochemical properties of the starch. In fact, Perez et al (2001) found that the starch from corn steeped for various time intervals presented an increase in peak temperature and a narrowing of the gelatinization range, due to the annealing produced during the steeping process.

The aim of the present work was to characterize the starch from corn kernels steeped in the presence of lactic acid and to determine the influence of the time of steeping. Pasting and thermal properties of the starch were analyzed by using the viscoanalyzer and differential scanning calorimetry (DSC), respectively. In addition, the size distribution of the starch granules was also assessed.

MATERIALS AND METHODS

Materials

A semi-dent corn, *Zea mays* cv. Tilcara, was harvested at an experimental farm of Facultad de Agronomía, Universidad Nacional de Luján, Buenos Aires, Argentina. The moisture content of the grain at harvest was 13.5 ± 0.2% dry basis. After appropriate cleaning, samples were stored at –18°C in sealed plastic bags until testing. Before assaying, the grain was kept overnight at ambient temperature. Chemical characterization of the samples was performed by determining moisture (AOAC 1980), protein (macro-Kjeldahl method, AOAC 1980), starch (Egan et al 1987), fat (Soxhlet extraction with petroleum ether for 24 hr), and ash content by calcination at 550°C. Starch, protein, oil, and ash contents were 10.1 ± 0.2, 81.1 ± 0.7, 4.0 ± 0.1, and 1.3 ± 0.1 g/100 g, db, respectively (mean ± standard deviation, *n* = 3).

Laboratory Wet-Milling

Starch was extracted following the laboratory wet-milling procedure described by Haros and Suarez (1999) and later modified by Perez et al (2001). Briefly, each batch of corn samples was steeped at 52°C in SO₂ solution (0.2%). Five steeping times were tested: 8, 16, 24, 32, and 40 hr (CS8, CS16, CS24, CS32, and CS40, respectively). To study the effects of lactic acid, the experiments were performed as described above but adding 0.5% (v/v) lactic acid (LAS8, LAS16, LAS24, LAS32, and LAS40, respectively).

Size Distribution of Starch Granules

Microscopic observations of the starch fraction were done with a light microscope (Axioplan, ZEISS, Jena, Germany). Starch (1.0 ± 0.1 mg) was dispersed onto a microscope slide, dyed with 0.1 mL of Congo-red solution (1%), and then covered with an upper slide. All samples were observed at 40× magnification. The diameters of

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starch granules were measured by means of the Greek-keeper technique using a microscope scale divided into tenths and hundredths. For each sample, 1,000 granules were observed and their diameters measured in micrometers (μm). Size distributions of starch granules were analyzed using histograms of observed frequencies (%) versus steeping time.

Damaged Starch Granules

Two different techniques were used: loss of birefringence and Congo-red staining. In the first, the characteristic Maltese cross was absent in the damaged granules. The second technique, described by Flint (1984), is based on the affinity of Congo-red stain to α 1-4 sugar bonds; consequently, damaged starch granules display strong red color.

Determinations of Pasting Properties

Pasting properties of starches were measured by using a Rapid Visco Analyser (RVA) (Newport Scientific Instruments, Warriewood, Australia), following the RVA corn starch method (AACC 2000). Corn starch (3.0 g, db) was suspended in distilled water (25 mL) and the suspension was thoroughly stirred in the RVA at 960 rpm for 10 sec and then at 160 rpm for the remainder of the test. The temperature was first maintained at 50°C for 1 min for equilibration and then raised to 95°C at 12°C/min. The sample was kept at 95°C for 2.5 min, cooled to 50°C at 12°C/min, and finally maintained at 50°C for 2 min. The experiments were conducted in duplicate and the average values were recorded with the standard deviation. The parameters recorded were pasting temperature (P_{temp}), peak time (P_{time}), peak viscosity (PV), trough or hot paste viscosity (HPV), final or cool paste viscosity (CPV), breakdown (PV - HPV), and setback (CPV - HPV). Breakdown viscosity is a measurement of the susceptibility of cooked starch to disintegration, and setback viscosity measures the degree of hardening of cooked starch during cooling (Chiang and Yeh 2002).

Differential Scanning Calorimetry (DSC)

DSC measurements were made with a Perkin-Elmer DSC-7 (Norwalk, CT). The calorimeter was periodically calibrated with indium (enthalpy of fusion 28.41 J/g, melting point 156.4°C). Starch (20–30 mg) was directly weighed into DSC stainless-steel pans (PE 0319-0218) and distilled water (2:1, water to flour) was added. After sealing, pans were heated from 30 to 120°C at 10°C/min, using an empty pan as a reference. The parameters measured were onset temperature (T_o), peak temperature (T_p), and conclusion temperature (T_c). Straight lines were drawn between T_o and T_c and the enthalpy associated with starch gelatinization (ΔH) was calculated as the area enclosed by the straight line and endotherm curve and expressed in J/g of dry sample. To analyze starch retrogradation, heated-cooled pans were stored at 4°C for two days, and then heated again in the calorimeter from 30 to 120°C at 10°C/min. Four replicates of all samples were analyzed. Small endotherms of 1–2 J/g were observed at 90–112°C for starch samples. These thermal transitions were attributed to the amylose-lipid complex in cereal starches (Koch and Jane 2000).

Lactic Acid Determination

Lactic acid from corn starch was extracted by suspending 0.1 g of starch in 1.0 mL of distilled water. The suspension was continuously stirred for 1 hr and then centrifuged at $13,200 \times g$ for 5 min. The L/D lactic acid content in the supernatant was determined using the enzymatic method described by Gutmann and Wahlefeld (1974).

RESULTS AND DISCUSSION

Influence of Steeping Conditions on Pasting Properties

The pasting properties of the control starch (from steeping in the absence of lactic acid) recovered from corn steeped for dif-

ferent times were determined. The viscosity profiles of corn starch from different steeping times were very similar (Fig. 1). Only a slight increase in pasting temperature was observed with increased steeping time, neither did the rest of the parameters change significantly, with the exception of the sample steeped for 40 hr, which showed a drop in the viscosity at cooling (CPV) (from 3,553 to 2,889 cP) and in setback from 1,585 cP (CS8) to 1,037 cP (CS40) by increasing the steeping time from 8 to 40 hr. The impact of SO_2 on the starch granules steeped for long time (40 hr) and starch damage or size distribution of granules might partially explain the differences observed with steeping time. However, the annealing during corn steeping plays an important role (Perez et al 2001). Previous studies have shown that the effects of annealing on pasting curves depend on the botanical source of starch and the instrument (Jacobs and Delcour 1998).

The addition of lactic acid during steeping caused considerable changes on the viscosity profiles of the corn starch (LAS) (Fig. 1). The LAS suspensions gave lower peak viscosities than corn starch samples steeped without lactic acid (CS). Lactic acid treatment reduced the pasting temperature by up to 3.2°C, whereas the peak time was reduced by up to 0.5 min (Table I). The decrease in peak viscosity was evident in the starch samples from corn steeped for >16 hr, showing a reduction up to 50% when steeped 40 hr. Decreases in hot paste viscosity (HPV), viscosity after cooling (CPV) and setback were observed after 8 hr of steeping. The greatest reduction was observed after 40 hr of steeping. Compared with the starch from corn steeped without lactic acid, HPV and CPV decreased by up to 83% and the setback from 1,037 to 181 cP (82%) when steeped in the presence of lactic acid. Similar results were obtained for corn and cassava starches when adding lactic acid (Shandera and Jackson 1996; Bertolini et al 2000), and for cassava starch after acid fermentation (Numfor et al 1995). This suggested that starch is degraded by lactic acid, thereby explaining the reductions in pasting properties (Shandera and Jackson 1996; Bertolini et al 2000) and increasing effects with increased steeping time. No lactic acid was found in the starch suspension (results not shown). Therefore, the degradation by lactic acid might occur in the kernels during steeping. According to Shandera and Jackson (1996), during steeping, lactic acid may diffuse into the granule during its hydration and swelling because the starch granules,

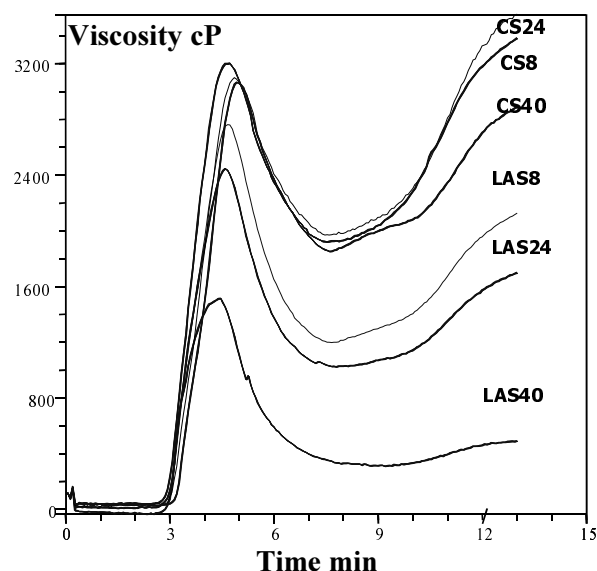


Fig. 1. Viscosity curves of corn starch measured with a Rapid Visco Analyser. CS8, CS24, and CS40 are starches from corn steeped for 8, 24, and 40 hr, respectively. LAS8, LAS24, and LAS40 are starches from corn steeped in lactic acid (0.5%, v/v) for 8, 24, and 40 hr, respectively.

although they are insoluble in water at subgelatinization temperatures (52°C), swell slightly and become partially hydrated (Waniska and Gomez 1992). However, BeMiller and Pratt (1981) reported that even the nongelatinized granule can be penetrated by and take up water and whatever ions or small molecules are dissolved in the water.

The amorphous phase of granular starch is heterogeneous, consisting of amorphous amylose and intercrystalline regions of dense branching in amylopectin (Biliaderis 1992). The later are easily susceptible to hydrolytic agents such as various enzymes and acids in solution (French 1984). Thus, the decrease in pasting viscosity of starch samples from corn steeped with lactic acid could result from decreased swelling due to partial depolymerization of amylopectin or amylose in the amorphous regions of starch granules (Camargo et al 1988; Shandera and Jackson 1996; Bertolini et al 2000). The water uptake during the steeping follows the diffusion equation based on Fick's law (Haros et al 1995; Haros and Suarez 1999). Longer steeping times results in an increase of the moisture content of the grain, being the moisture content uniform into the kernels after 30–40 hr, depending of the type of grain. In wet-milling, the grains are steeped in warm water, which gradually changes the volume by swell. The lactic acid was carried by the water into the kernels, so higher steeping time magnifies the effect of lactic acid by increasing the amount of lactic acid absorbed into the corn kernels.

Thermal Properties of Starch from Corn Steeped with Lactic Acid

The thermal properties of corn starch were affected by grain steeping conditions. Steeping time was the major factor affecting the thermal properties of the corn starch, producing an increase in the peak temperature and a narrowing in the gelatinization range (results not shown). However, the addition of lactic acid in steeping did not promote any further changes in thermal properties. Those results were similar to the findings of Perez et al (2001) when corn kernels were steeped in SO₂ solution alone for various intervals; they attributed the changes to the annealing of starch during steeping. However there is no information on the retro-

gradation behavior of the starch as affected by different steeping conditions. The retrogradation of corn starch was evaluated by measuring the transition temperatures and the enthalpy of the retrogradation endotherm (ΔH) after two days of storage at 4°C. To accelerate recrystallization, a high amount of water (66.7%) was added to the starch samples because 50% has been attributed to maximum recrystallization (Longton and Legrys 1981). The retrogradation transition temperatures were not modified by the steeping conditions (Table II). The enthalpy of starch retrogradation progressively decreased with increasing steeping time from 8 to 40 hr (4.91 J/g in CS8 to 4.21 J/g in CS40). The same tendency was observed with lactic acid (4.64 J/g in LAS8 to 4.05 J/g in LAS40). The retrogradation index (RI) was defined as $(\Delta H_{\text{retrogradation}}/\Delta H_{\text{gelatinization}}) \times 100$. Decreased transition enthalpy was also reflected in the retrogradation index, which declined from 45 to 38 for the samples steeped for 8 and 40 hr, respectively.

Retrogradation involves rapid crystallization of amylose and slow recrystallization of amylopectin (Biliaderis 1992). The addition of lactic acid to the steeping solution had a minor influence on retrogradation because the same behavior was observed without lactic acid, and the determinant was the duration of the steeping process.

The only evident change with lactic acid was a slight decrease in retrogradation enthalpy, likely due to partial hydrolysis promoted by the lactic acid, which would lead to a decrease in the average amylopectin molecular weight. In consequence, less energy is required for recrystallization. However, physical changes such as damaged starch or starch granule size might also have contributed.

With regard to the melting temperature of the amylose-lipid complex, no change was observed with increased steeping time nor with incorporating lactic acid in the steepwater (Table III). Nevertheless, a slight decrease in the transition enthalpy was observed in the starch from kernels steeped with lactic acid, indicating a reduced amount of amylose-lipid complex. The decrease of enthalpy was between 10 and 25%. The modification of the granule structure was feasible by complexing amylose with lipids; such inclusion complexes can exist in various aggregated forms

TABLE I
Pasting Properties of Starch Obtained by Wet-Milling with Lactic Acid for Different Steeping Times^a

Name	Steeping Time (hr)	P _{temp} (°C)	P _{time} (min)	Viscosity (cP)				
				PV	HPV	CPV	Breakdown ^b	Setback ^c
LAS8	8	71.9 ± 0.1	4.67 ± 0.01	2,763 ± 92	1,196 ± 13	2,124 ± 11	1,567 ± 94	928 ± 2
LAS16	16	71.1 ± 0.7	4.60 ± 0.01	3,058 ± 18	1,176 ± 18	2,133 ± 21	1,882 ± 36	957 ± 1
LAS24	24	71.8 ± 0.2	4.60 ± 0.05	2,447 ± 20	1,025 ± 3	1,700 ± 7	1,422 ± 17	675 ± 1
LAS32	32	72.7 ± 0.1	4.73 ± 0.01	2,276 ± 99	885 ± 37	1,491 ± 85	1,391 ± 26	606 ± 4
LAS40	40	72.6 ± 0.5	4.47 ± 0.04	1,515 ± 57	310 ± 6	491 ± 7	1,205 ± 50	181 ± 1

^a P_{temp}, pasting temperature; P_{time}, peak time; PV, peak viscosity; HPV, hot paste viscosity; CPV, cool paste viscosity; LAS, corn starch steeped in the presence of lactic acid at different times. Mean ± standard deviation (n = 2).

^b PV – HPV.

^c CPV – HPV.

TABLE II
Retrogradation Parameters of Starch Obtained by Wet-Milling Steeped With and Without Lactic Acid at Different Times^a

Samples	Steeping Time (hr)	T _o (°C)	T _p (°C)	T _c (°C)	ΔH (J/g)	RI
CS8	8	43.6 ± 0.8	55.0 ± 0.7	66.9 ± 0.1	4.91 ± 0.71	45.1
CS16	16	46.4 ± 0.2	56.9 ± 0.1	67.5 ± 0.1	4.32 ± 0.26	39.2
CS24	24	47.3 ± 0.3	58.2 ± 0.9	67.1 ± 0.4	4.51 ± 0.12	40.7
CS32	32	48.6 ± 0.7	59.2 ± 0.7	68.2 ± 0.6	4.26 ± 0.22	39.3
CS40	40	48.7 ± 0.7	58.2 ± 0.9	68.1 ± 0.1	4.21 ± 0.07	38.2
LAS8	8	44.9 ± 0.5	56.3 ± 0.3	67.2 ± 0.1	4.64 ± 0.23	44.9
LAS16	16	47.2 ± 0.4	57.9 ± 0.3	67.9 ± 0.5	4.36 ± 0.57	42.4
LAS24	24	46.1 ± 0.4	57.3 ± 0.2	67.1 ± 0.4	4.51 ± 0.19	44.1
LAS32	32	47.3 ± 0.3	57.8 ± 0.2	67.3 ± 0.6	4.21 ± 0.15	40.5
LAS40	40	47.6 ± 0.2	58.0 ± 0.4	67.4 ± 0.3	4.05 ± 0.01	37.9

^a T_o, onset temperature; T_p, peak temperature; T_c, conclusion temperature; ΔH , retrogradation enthalpy; RI, retrogradation index; CS, corn starch from different steeping times; LAS, corn starch steeped in the presence of lactic acid at different times. Mean ± standard deviation (n = 4).

depending on the thermal and mechanical history of the product (Biliaderis 1992). The samples steeped with lactic acid would have reduced size, decreasing in some extent, the ability to form the amylose-lipid complex.

Effect of Steeping Conditions on Starch Recoveries, Granule Size Distribution, and Damage

Starch granules observed by light microscopy were more or less spherical and polyhedral shaped, and showed diversity in size. There were several differences in the physical properties of the starch samples recovered from corn steeped with lactic acid for different times and those of starches recovered from kernels steeped without lactic acid for different times (Tables I–III). Corn kernels steeped in SO₂ solution gave increased starch recoveries as steeping time increased (Table IV), which was attributed to the ability of SO₂ to disperse the protein matrix surrounding starch granules (Haros et al 1995) with increased steeping time, more water, and SO₂ diffused into the kernels softening the endosperm, which resulted in high recoveries and reduced amount of damaged starch.

Corn grains steeped in SO₂ and lactic acid gave much higher starch recoveries than did corn steeped in SO₂ alone (Table IV). The lowest starch recovery was obtained from corn steeped for 8 hr with lactic acid was higher than the one obtained after 40 hr of steeping without lactic acid. The positive effect of lactic acid has been attributed to its action on cell walls of corn endosperm (Roushdi et al 1981). Lactic acid also enhances SO₂ absorption within kernels, facilitating dispersion of the protein matrix in which starch granules are embedded (Shandera et al 1995), especially the starch granules of the horny endosperm (Haros and Suarez 1999). Dailey (2002) reported that protein release was consistently higher when lactic acid was included in the steepwater, providing strong evidence that it enhances protein solubilization (Perez et al 2001). However, protein content of starch had a range 0.56–0.63%, db. There was no significant difference in protein content for all treatments.

Steeping time affected size distributions of starch granules. Data for each starch sample were divided into two size ranges, <12 μm and >12 μm, and reported as percentages of the total number of granules measured (Table IV). The sample from 8 hr of steeping gave a starch with only 2% of granules smaller than 12 μm, whereas that percentage increased up to 20 and 40% in the samples steeped for 16 and 24 hr, respectively. That result is greater starch recovery from horny endosperm where granules are smaller (Le Bras 1982). Seetharaman et al (2001) reported that the variability in thermal and functional attributes was related to amylose content and starch granule size.

The damaged starch content was considerably reduced by lactic acid. Damaged starch was also reduced by increasing steeping time but, in the presence of lactic acid, the content of damaged starch was lowest (≈1%) even at the shortest steeping time (8 hr). Robutti et al (1974) proposed that starch from horny endosperm was more prone to damage during milling because of stronger adhesion between the matrix protein and starch granules, especially when steeping time was not sufficient for totally wetting the grains before milling. Lactic acid addition promotes water and SO₂ diffusion, accelerating the wetting process and the dispersion of the protein matrix (Haros and Suarez 1999).

CONCLUSIONS

Increasing the steep time from 8 to 40 hr significantly improved the separation between corn components, indicated by a higher starch recovery. The presence of lactic acid in the steepwater greatly improves the starch recovery from corn kernels, likely due to easier diffusion of SO₂ in addition to the breakdown of the protein matrix. As a result, an important reduction in steeping time can be obtained. Lactic acid hydrolyzes the starch, reducing viscosities of the starch suspensions, and slightly decreasing amylopectin retrogradation and melting enthalpy of the amylose-lipid complex. Hydrolysis of the starch during steeping seems the

TABLE III
Amylose-Lipid Complex Transition of Starch Obtained by Wet-Milling Steeped With and Without Lactic Acid for Different Times^a

Samples ^b	Steeping Time (hr)	T _o (°C)	T _p (°C)	T _c (°C)	ΔH (J/g)
CS8	8	90.1 ± 0.2	103.2 ± 0.9	112.0 ± 0.2	1.55 ± 0.04
CS16	16	91.4 ± 0.7	104.0 ± 0.2	113.2 ± 0.5	1.57 ± 0.06
CS24	24	91.0 ± 0.7	104.8 ± 0.3	111.4 ± 0.1	1.48 ± 0.05
CS32	32	91.4 ± 0.1	104.9 ± 0.6	112.8 ± 0.8	1.45 ± 0.04
CS40	40	91.6 ± 0.5	104.5 ± 0.7	112.1 ± 0.9	1.42 ± 0.02
LAS8	8	92.9 ± 0.2	103.0 ± 0.2	111.6 ± 0.2	1.37 ± 0.01
LAS16	16	91.3 ± 0.9	105.5 ± 0.5	111.5 ± 0.3	1.22 ± 0.26
LAS24	24	91.4 ± 0.8	104.7 ± 0.7	111.5 ± 0.2	1.17 ± 0.11
LAS32	32	91.9 ± 0.9	104.0 ± 0.4	111.9 ± 0.2	1.31 ± 0.02
LAS40	40	91.3 ± 0.1	104.2 ± 0.7	111.5 ± 0.6	1.06 ± 0.02

^a T_o, onset temperature; T_p, peak temperature; T_c, conclusion temperature; ΔH, enthalpy.

^b CS, corn starch from different steeping times; LAS, corn starch steeped in the presence of lactic acid at different times. Mean ± standard deviation (n = 4).

TABLE IV
Properties of Starch by Kernels Steeped at Different Times With and Without Lactic Acid

Lactic Acid (% v/v)	Steeping Time (hr)	Starch		Particle Size Distribution						
		Recovery (% db)	Damaged Starch (%)	Minimum (μm)	Maximum (μm)	Range (μm)	<12 μm (%)	>12 μm (%)	Mean Diameter (μm)	Distribution SD (μm)
0	8	79.8±0.2	30.5±0.9	7.3	43.5	36.3	2	98	22.8	7.06
	16	82.6±0.3	8.4±0.7	4.8	24.2	19.3	20	80	14.5	4.53
	24	83.7±0.1	19.0±0.7	4.8	29.0	24.2	40	60	13.2	5.08
	32	84.1±0.5	6.4±0.8	3.6	26.6	23.0	32	68	13.3	4.92
0.5	40	85.1±0.2	5.8±0.9	2.4	33.8	31.4	38	62	14.1	7.20
	8	89.3±0.4	1.2±0.6	4.8	29.0	24.2	46	54	12.5	5.20
	16	90.6±0.2	2.6±0.8	4.8	21.8	16.9	41	59	11.9	4.39
	24	92.4±0.3	0.4±0.0	4.8	24.2	19.3	22	78	14.6	4.45
	32	92.6±0.5	1.6±0.6	2.4	24.2	21.8	30	70	13.2	4.29
	40	94.9±0.4	1.5±0.1	2.4	24.2	21.8	47	53	12.1	4.64

^a Mean ± standard deviation (n = 4).

most probable explanation to the starch modifications produced by lactic acid addition.

The economic factors of increasing steep time to improve starch recovery and the addition of lactic acid have to be taken into account. It might have important implications in the consistency of starch physicochemical properties and, consequently, in the quality of food products added with starch, depending on processing conditions, ingredients, and storage requirements. However, steeping time and steep water with lactic acid provoked important changes in the starch properties, which may affect their final use in processed foods.

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